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ABSTRACT

A computer-based instructional system is described which incorporates diagnosis of students difficulties in acquiring complex concepts and skills. A computer automatically generated a simulated display. It then monitored and analyzed a student's work in the performance of assigned training tasks. Two major tasks were studied. The first, maintaining an aircraft in a holding pattern solely through instrument indicators, involved perceptual motor skills. A monitor system for this task was implemented and used with both new and experienced pilots. The second task area involved the acquisition of those perceptual skills essential to ship maneuvering and collision avoidance. A graduated sequence of course estimation problems presented on a screen permitted both the gradual acquisition of skills and isolation of conspicuous learning difficulties. On the basis of the latter studies, a framework was constructed for detecting those deeper underlying difficulties which show up in more complex and realistic maneuvering situations. Implications for the development of improved methods of behavior modification and their incorporation in training programs are discussed. (Author/JY)

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CONSULTING · DEVELOPMENT · RESEARCH

Report No. 2272

AUTOMATED INSTRUCTIONAL MONITORS FOR COMPLEX OPERATIONAL TASKS

Final Report

Principal Investigator
Wallace Feurzeig

October 31, 1971

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13. ABSTRACT This report describes research on computer-based instructional techniques incorporating diagnosis of student difficulties in acquiring complex concepts and skills. A computer automatically generates a simulated display. It then monitors and analyzes a student's work in the performance of assigned training tasks -- hypotheses describing specific learning difficulties are tested and appropriate advice is given. Two major task areas were studied. The first, maintaining an aircraft in a holding pattern solely through instrument indicators, involved perceptual motor skills. A monitor system for this task was implemented and used with both new and experienced pilots. The second task area involved the acquisition of those perceptual skills essential to ship maneuvering and collision avoidance. A graduated sequence of course estimation problems presented on a simulated PPI screen permitted both the gradual acquisition of skills and isolation of conspicuous learning difficulties. On the basis of the latter studies, a framework was constructed for detecting those deeper underlying difficulties which show up in more complex and realistic maneuvering situations. Implications for the development of improved methods of behavior modification and their incorporation in training programs are discussed.

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1. Introduction

The objectives of this research were stated in the initial proposal, submitted August 5, 1968:

> Skills such as maneuvering and navigation are too complex to be taught through standard computer-assisted instructional lessons. The procedures to be taught are richer and more varied, and the scope of student learning difficulties much greater, than those encountered in teaching simpler skills such as stenotypy or telegraph keyset operation. To handle these harder problems effectively, an instructional program must include procedures enabling the computer to diagnose the student's learning difficulties as he tries to carry out the tasks being taught. To do this, the computer must be given a means of tracking a student's behavior and of generating and testing hypotheses about his difficulties. We plan to investigate the incorporation of these capabilities in a computer program called an automated instructional monitor.

We described a three-year program of research on computer-based instructional techniques incorporating diagnosis of student difficulties in acquiring complex concepts and skills in performing operational tasks. The work was to extend earlier research with a simple student monitoring program, SIMON, which was able to test the validity of a student's programmed procedure for performing a task but was not able to diagnose any errors made along the way. In the new approach, the computer would automatically generate a dynamic display representing the simulated task. The student would communicate with the computer through the display or keyboard in the course of performing the task. As he did so, the monitor system would track and analyze the student's work. Hypotheses describing specific learning difficulties would be tested and appropriate advice given.

During the first year we sought to build the component programs needed for such an instructional monitor. These included programs for representing the training task and situation in a suitably realistic simulation, programs for diagnosing trainee actions including erratic behaviors, and dialogue programs to enable communication between the trainee and the system. We planned during the second year to integrate the components into an effective monitor system and to apply it in an elaborate extended training situation. The final year was to involve evaluation of the material produced in an actual training situation and investigation of the problems involved in applying the monitoring techniques thus far developed to other operational training tasks.

The operational training tasks of particular interest to us were in the areas of naval maneuvering, instrument flying, and navigation. We selected the first two of these areas. The first task chosen was a perceptual motor task: maintaining a simulated aircraft in flight on a holding pattern over a prescribed course while guided solely by standard flight instrument indicators (i.e., without visual sighting of the real scene). The second area of work involved those perceptual skills underlying maneuvering board work: estimating the relative courses of ships moving at varied rates and in various configurations. Naval maneuvering and collision avoidance skills were the objects of our interest here.

An instructional monitor for the holding pattern test was designed, implemented, and tested with instrument flight trainees. This work is described in Section 2. A program for generating and presenting maneuvering problems on a simulated PPI screen was designed and implemented. Using this, a graduated sequence of course estimation problems was presented to a number of subjects. By studying and analyzing trainee behaviors, we characterized conspicuous learning difficulties and patterns of skill acquisition. This work is described in Section 3. In Section 4 we discuss implications of the work done in both areas for further research and application.

Several persons collaborated in this study. The task simulations, training experiments, and associated computer programs were designed by Wallace Feurzeig, George Lukas, Patrick McHugh, and Paul Wexelblat. In the holding pattern work, the training problems were provided by McHugh, an experienced instrument flight instructor. McHugh also supervised the flight testing of the trainees. Feurzeig and Wexelblat designed the instructional monitors. The programming was done by Wexelblat, with some assistance from Philip Faflick and Richard Grant. Seymour Papert contributed to the early planning phase of this work. In the ship maneuvering work, Lukas designed and analyzed the experiment, and Wexelblat wrote the computer programs.

The report was written by Feurzeig and Lukas and edited by Pearl Stockwell.

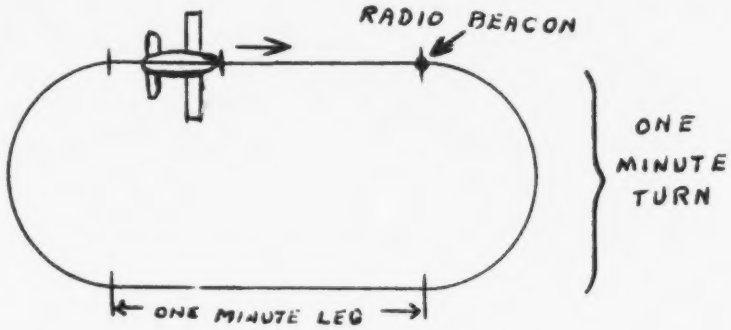
2. Instructional Monitors and the Holding Pattern Task

Investigating the use of computers to help teach complex skills such as ship maneuvering and instrument flying was the overall aim of this project. Our general approach was to design a highly task-specific system of programs (called an instructional monitor) for following a student's work and diagnosing his difficulties along the way. Such a monitor requires detailed information on the different kinds of errors possible, procedures for diagnosing specific errors in terms of observable local and global effects, and associated information about possible reasons for errors in faulty procedures or conceptualization to serve in taking corrective action.

Our personal experiences provided a rich source of pertinent error diagnostic information for the holding pattern task in instrument flight training. We therefore decided to use that task as the initial context for carrying out monitor design and experimentation.

2.1 The Real Task

One of the major tasks in instrument flying is maintaining a holding pattern. The basic holding pattern maneuver is quite straightforward: the path is a simple oval consisting of a leg that is flown for one minute inbound to a radio beacon, a one-minute 180° turn to the right, an outbound one-minute leg, another one-minute 180° turn to the right, and this pattern is repeated.



Realistic complications of the maneuver often confuse the student. The apparent complexity occurs when he realizes that the pattern is rarely laid out neatly east-west or north-south, that there is a wind from some direction, possibly changing in velocity and direction, and that there is an overriding necessity to keep the aircraft flying as well as maneuvering.

The greatest single problem throughout the student's initiation into holding patterns is that of keeping his orientation. It is exceptionally easy for a beginning student to forget where he is in the pattern, what he is trying to do, and what he is to do next. Without a good mental picture of this, his efforts will

fail. An essential aspect is a proper instrument scan -- avoiding disorientation is crucial and a good instrument cross check is a key factor in avoiding disorientation. (The standard instruments include a gyrocompass, automatic (radio) direction finder (ADF), rate-of-turn indicator, altimeter, and clock.)

To indoctrinate the student, holding patterns should be flown visually at first. As the instruction progresses the student will realize that his only fixed "landmark" is the radio beacon. He cannot see it, but his instruments can. He must have a reasonable idea of what instrument indications to expect at various points in the pattern before initiating the hold. Given this preplanning, the deviations caused by winds are explicable and readily assimilated.

Typical holding pattern errors made by trainees include the following.

1. Failure to pre-plan the entry before arriving at the hold area, resulting in disorientation and improper entry.

2. Holding on the side opposite that for which the clearance was issued.

3. Slowing of the cross check after arriving at the fix and subsequent disorientation.

4. Uncorrected drift pattern due to failure to visualize the wind effects.

5. Failure to start timing the outbound leg when abeam the station.

6. Varying the bank angle on inbound or outbound turns.

7. Failure to adjust the outbound leg to assure a one-minute-long inbound leg.

8. Confusion due to forgetting inbound and outbound headings, corrected headings, or wind direction and speed.

9. Inability to visualize probable ground track.

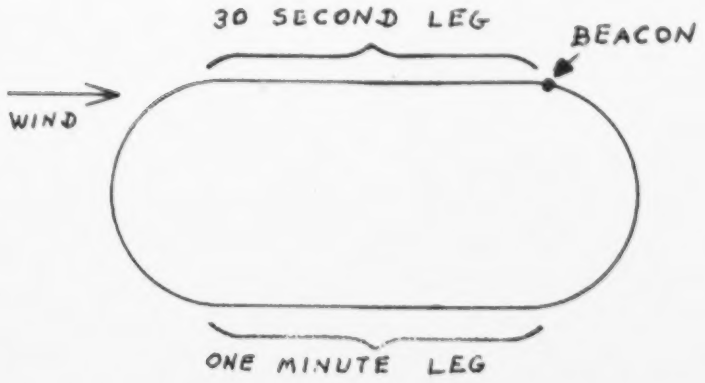
10. Failure to see the necessity to vary drift corrections when they do not work out as expected.

11. Fixing attention on a single aspect of the problem resulting in a general deterioration.

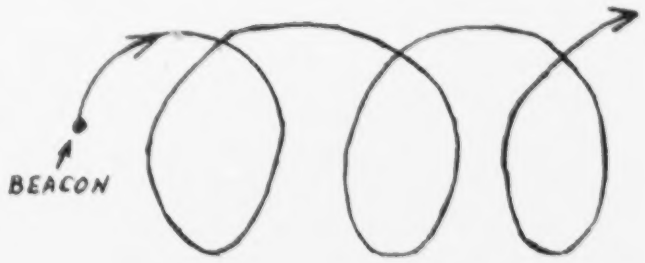
12. Failure to maintain attitude.

13. Failure to hold centerline when inbound to the beacon.

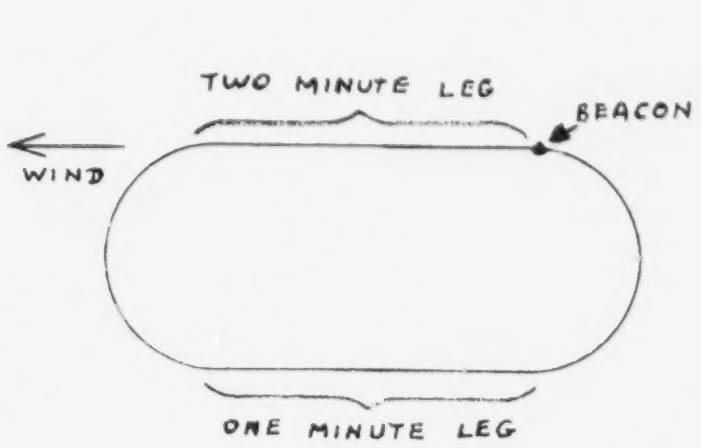
The following incorrect paths, which are representative of early student work, occur as a result of the indicated errors.



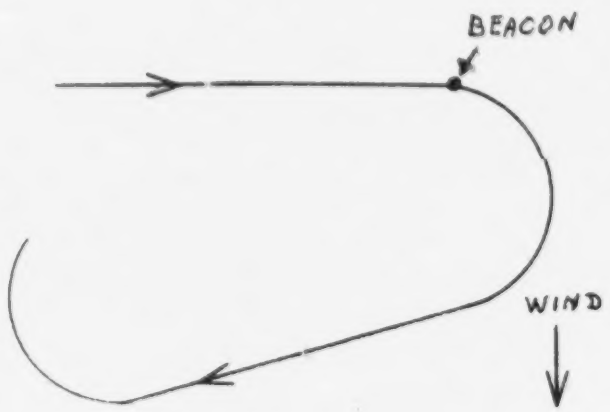
Inadequate compensation for outbound headwind resulting in too short inbound leg.



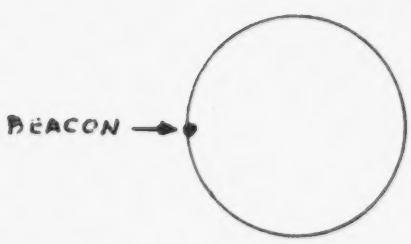
Constant bank with wind.



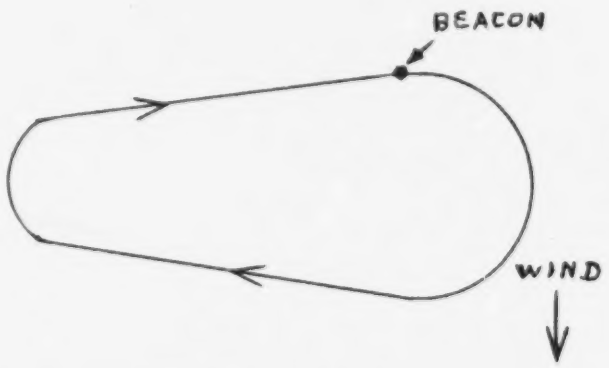
Not shortening outbound leg to compensate for tailwind on outbound leg, resulting in an overly long inbound leg.



No wind correction angle on outbound leg.

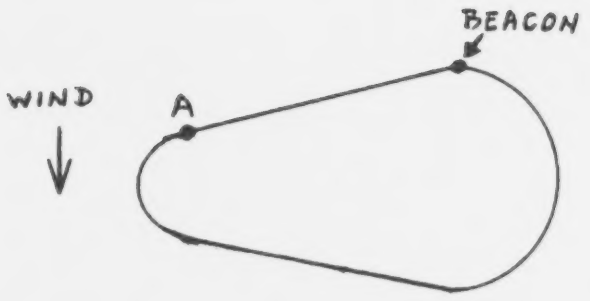


Constant bank.

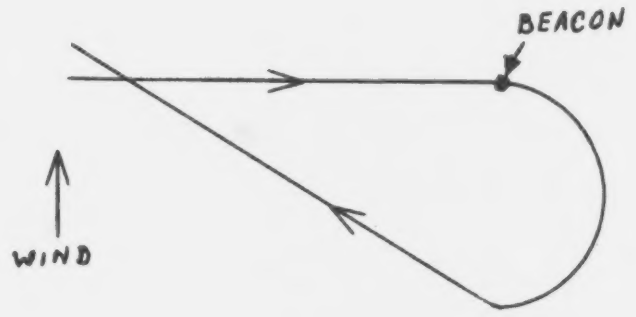


Outbound leg too short, turn to inbound leg poorly planned.

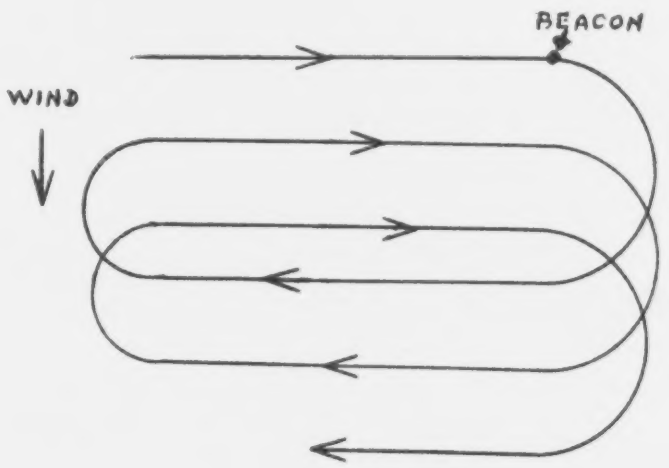
Haphazard wind correction.



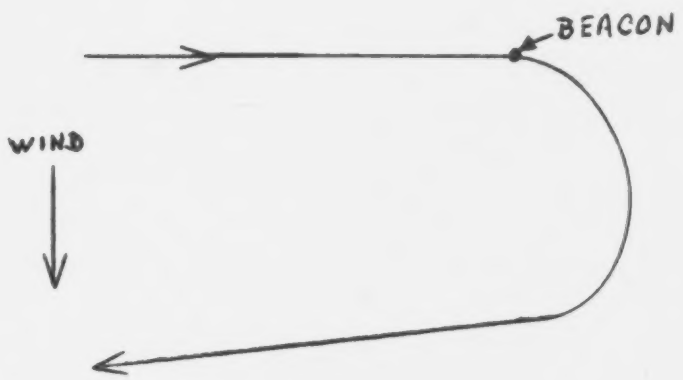
Confusion after turning inbound and not finding expected instrument indications. Flying directly from point A to the beacon.



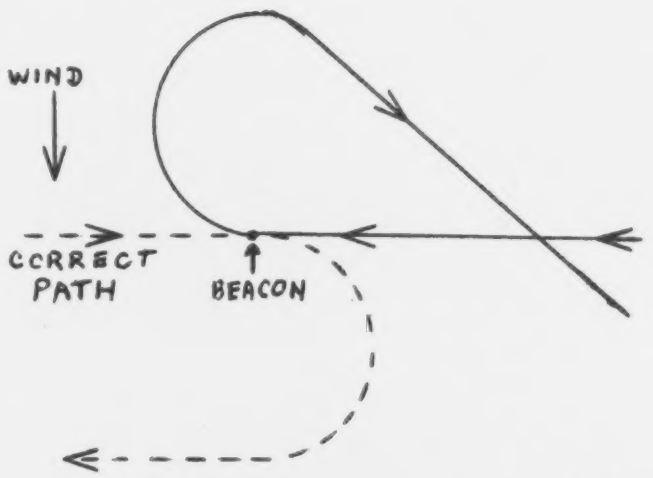
Wind correction angle applied in wrong direction on outbound leg with wind from the east.



Correct wind correction angle but no "double drift" correction. Failure to realize problem for some time.



Wind correction angle applied in wrong direction on outbound leg with wind from the west.



Holding on wrong side with proper wind correction angle.

2.2 The Simulated Task

In the simulation, the trainee has the task of "flying a vehicle" over a prescribed course on the basis of instrument information. The vehicle is represented as a moving point on a scope which also displays the appropriately changing instrument information. The location of the vehicle, the ground track for the course, the instrument indicators, and the trainee's actual flight path can all be displayed. (In later phases, only the instrument indicators are shown.) The trainee controls the vehicle through use of a joystick linked to the computer. The problem may be complicated by the introduction of winds, drift on the controls, and variations in altitude. All of this is represented in a set of programs implemented on an SDS-940 time-shared computer system. The main simulation and display programs are:

1. Instrument generation and display programs
2. Holding pattern display program
3. Ground track display program
4. Joystick control program
5. Wind program
6. Altitude drift program
7. Holding pattern orientation program.

The Instrumert Display Programs

The display consists of four instruments: altimeter, ADF (Automatic Direction Finder), magnetic compass, and rate-of-turn indicator.

The altimeter simply records the distance above an imaginary sea level. A built-in pseudo-random drift factor on altitude keeps the plane either rising or falling slowly. This does not correspond to the workings of a "real" plane, but the additional task of maintaining a given altitude against the random drift creates distractions like those involved in actual flying.

The ADF dial provides relative bearing information. It is programmed to point towards a fixed radio beacon on one of the corners of the holding pattern. Thus, the direction the needle points at any time gives the bearing from the aircraft to the station (beacon).

The student determines his direction of flight through the use of the magnetic compass. The direction the needle points is the aircraft's absolute bearing. Under heavy crosswind conditions, the student must learn to "crab"-to add a corrective slice to his compass heading-if he is to offset the effect of winds and stay on course.

The last instrument on the "panel" is the rate-of-turn indicator. This dial tells the pilot how steeply and to which side the plane is banking by displaying the rate-of-turn of his current bank. There are three marks on the dial corresponding to standard-rate left turn, level flight, and standard-rate right turn, respectively. As with the compass, the student must learn to anticipate the effect of a crosswind on his ground speed during a turn and make the appropriate adjustments in his flight plan.

The Holding Pattern/Ground Track Display Programs

These programs display a stationary bird's-eye view of the imaginary holding pattern including the standard check points and the actual course of the plane. The extent of the actual flight track shown can be varied. The entire course can be shown or just contrails indicating the present location. As well, the track can be made invisible. After the student's initial indoctrination to the joystick and dials, this display is turned off simulating the "under the hood" situation. After the completion of a flight, regenerating the display of the entire track is useful for providing a quick summary of the student's performance.

The Joystick Control Program

The trainee "flys" the vehicle by operating a joystick device with two control axes:

(1) The forward and back axis controls the altitude
(2) The left and right axis controls the bank of the plane.

Positional information from the joystick is converted into digital data by the use of an analog-to-digital converter. In addition, a clock interrupt system was implemented to insure real-time operation within a time-shared computer environment. Thus, computer elapsed time and actual flying time are guaranteed equal regardless of the load (number of active users) on the computer.

Control over the mock aircraft is maintained by operator manipulation of the joystick. The operator can determine the rate of bank, and thus the rate of turn, by moving the joystick to the right or left. The rate of bank increases at a speed proportional to the throw of the joystick. The rate of climb or descent (altitude) is determined by the forward and backward movement of the joystick with the center position corresponding to level flight.

Wind Program

This program permits adding a constant wind from any direction and with any speed from zero up to the plane's airspeed. Flying a holding pattern with a crosswind half the speed of the aircraft is a challenging problem for even experienced pilots. Gusts and winds of non-constant speed varying around a specified average and range, and shifting in direction, can be introduced.

Altitude Drift Program

This introduces a pseudo-random variation around the nominal altitude.

Holding Pattern Orientation Program

This permits the orientation of the holding pattern to be rotated -- the inbound heading can be set to any value from 0° to 359°. Figure 1 shows the instrument display along with a holding pattern having an orientation of 137° off the standard vertical presentation. The four instrument indicators, from top to bottom, are the altimeter, radio direction finder, compass, and rate-of-turn indicator.

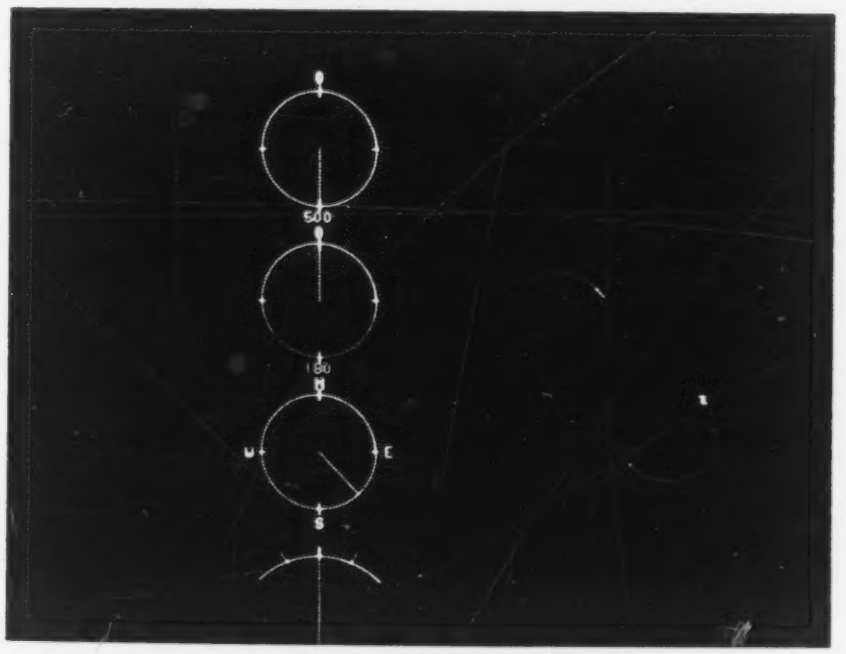


Fig. 1. Display of Instruments and Rotated Holding Pattern.

Figure 2 shows the console equipment - the display, teletypewriter, and joystick control. A close-up of the joystick is shown in Figure 3.

Fig. 2. Console Arrangement

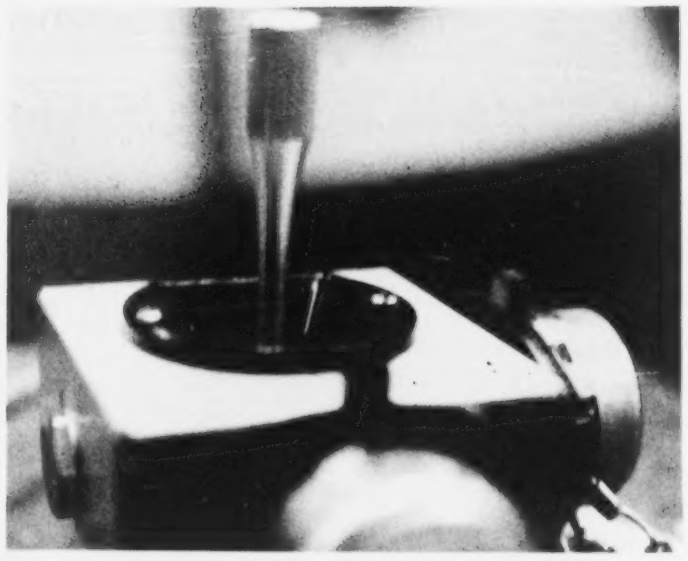


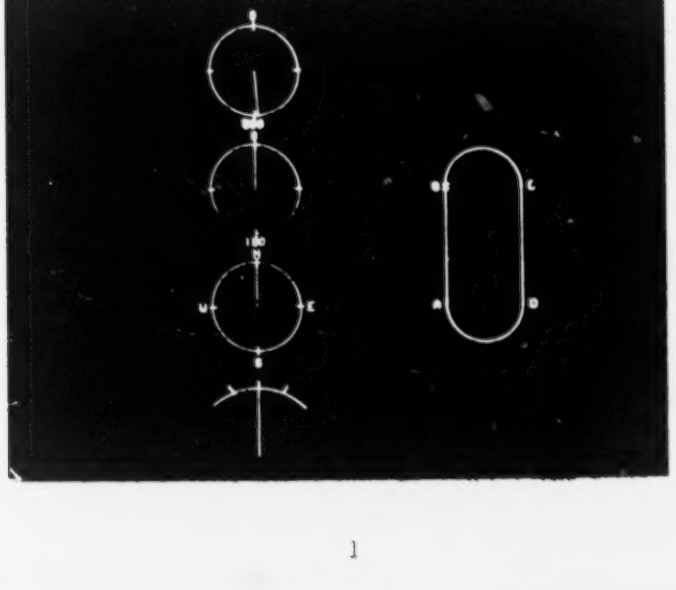
Fig. 3. Joystick Control

2.3 Operation of the Monitor Programs

The use of the programs just described is illustrated next with a simple flight indoctrination problem. The situation starts with standard initial conditions: no wind, inbound heading of Ø°, the aircraft flying due north along path A-B (see Fig. 4.1). The altimeter points to 500, the altitude assigned for this problem, the compass points to north, the ADF places the beacon (located at B) directly ahead, and the rate-of-turn indicator says the plane is flying level. Under no-wind conditions, each of the legs (A to B, B to C, C to D, and D to A) takes one minute to fly. Figures 4.1 - 4.6 are photographs taken at approximately 40-second intervals as a student gains familiarity with the instruments. The holding pattern and flight path are displayed during this phase. The changing path contrasts clearly with the fixed pattern.

As the student proceeds in his flight, the state of the four dials and the position of the plane at each clock interrupt (usually every 1/2 second) are stored in the computer. When he is through, the student may review his flight in its entirety by calling on the replay monitor. This program "plays back" the flight, displaying both the instruments and the holding pattern along with the ground track.

As well as reproducing the flight path and all associated instrument readings, the replay monitor attempts to detect the trainee's local errors and make appropriate comments. The trainee starts the replay monitor after carrying out his flight. The monitor regenerates his flight, stopping at various points



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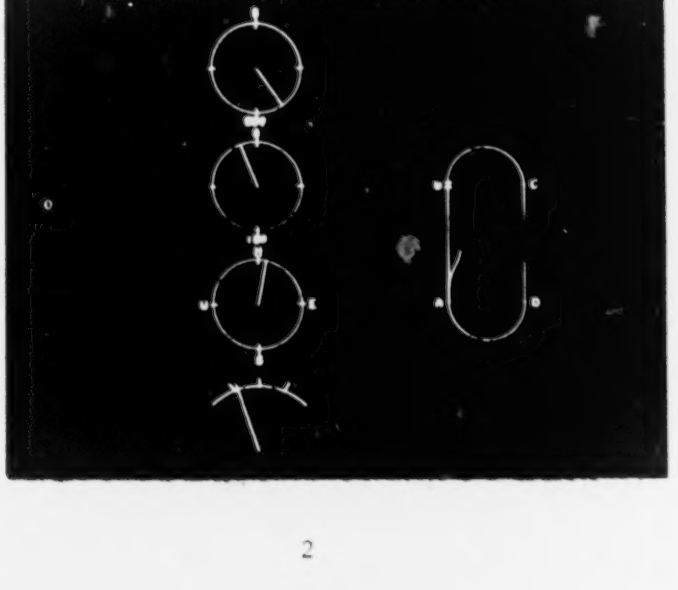

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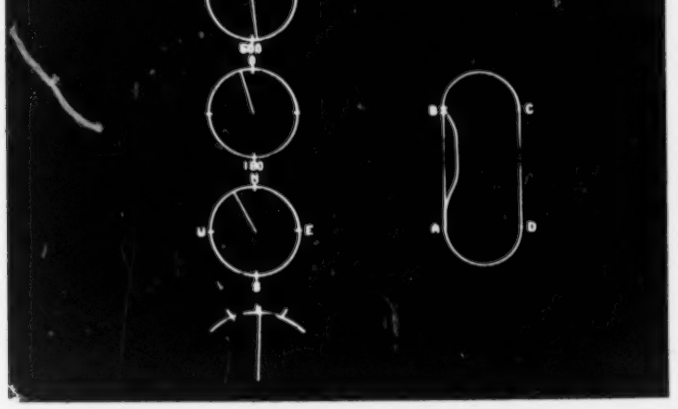

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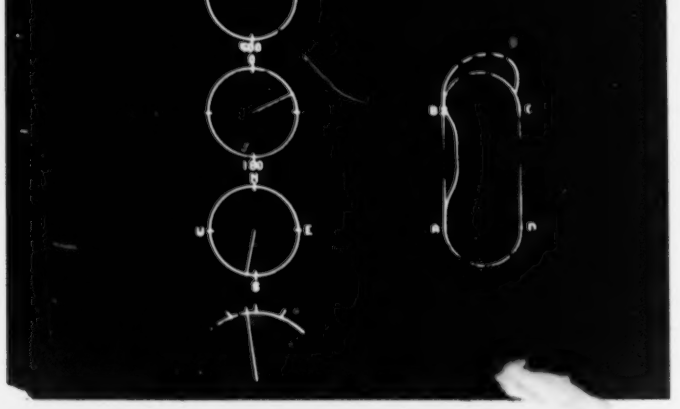

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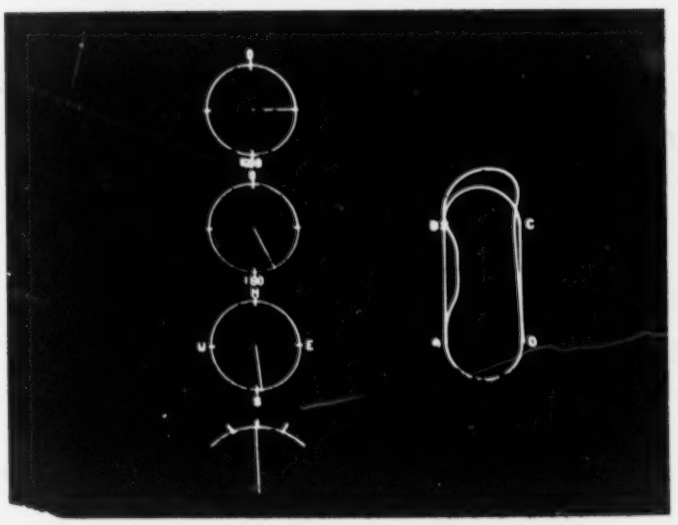

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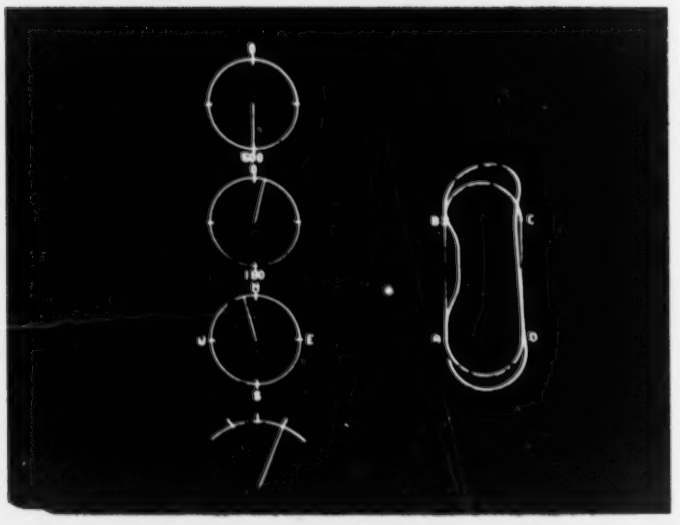

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Fig. 4. Early Flight Indoctrination Sequence

along the way to make error comments. Each time it makes a comment, the monitor freezes the display -- the trainee resumes operation after he has noted the comment and studied the display.

The operation of the replay monitor is illustrated using the flight sequence shown in Fig. 4. Figure 4.1 shows the initial view seen by the trainee. Within about five seconds of starting, the trainee veered off course by initiating a bank towards the right. The monitor interrupted with the comment

NOTE RATE-OF-TURN INDICATOR
YOU SHOULD NOT HAVE BANKED RIGHT

Figure 4.2 shows the trainee taking corrective action by banking to the left. But, he has overcorrected. Before the trainee initiated the sharp left which got him back to the beacon (Fig. 4.3), the monitor stopped the action with the comment

YOU SHOULD HAVE CONTINUED BANKING TO LEVEL OFF

The trainee has just made it back to the beacon but, in doing so, he has left himself in very poor position to initiate his bank towards the right for the top loop of the pattern. He should now be into his right bank.

The trainee, realizing that his right turn is too wide (Fig. 4.4) tries to compensate by tightening up his turn so that he will come out at Point C, but he over-adjusts, and comes out too far inside. The monitor comments:

ACCORDING TO THE COMPASS YOU ARE HEADING SOUTHWEST
THE ADF TELLS YOU THAT THE BEACON IS AHEAD OF YOU AND TO YOUR RIGHT
TOO TIGHT BANK

In the straight leg C - D, the trainee strays somewhat off the pattern. Figure 4.5 shows that he has passed point D and still has not turned. This time, as well as commenting on the state of the instrument indicators, the monitor declares:

CORRECTIVE ACTION REQUIRED AT THIS TIME

As Fig. 4.6 shows, the trainee took appropriate action by making a good right turn which is leading right back to the starting point A.

The replay monitor works by projecting the trainee's current actions to assess likely outcomes. It attempts to recognize aberrant actions like making a bank in the wrong direction or at the wrong time. But, it does not analyze these actions globally to try to describe the trainee's entire performance. To help

characterize the trainee's underlying difficulties in terms of standard holding pattern errors, we designed another program, an analytic monitor. Like the replay monitor, the analytic monitor is used after the termination of a training session. Its operation is, however, quite different. It carries out a post-mortem of the flight in which it tries to match the pattern of actual errors made by the trainee throughout the sequence with the characteristic patterns describing standard holding pattern errors like those listed in Section 2.1.

The operation of the analytic monitor is illustrated with an actual example in a problem incorporating winds. Figure 5 shows photographs from the flight sequence. The instructor, in setting up the problem, called the wind program. He gave it three inputs which specified the wind type as constant, with a 90° heading (i.e., out of the west) and a velocity of 10 knots, a moderate level (the speed of the plane is 100 knots).

A student then flew the sequence excerpted in Figs. 5.1 - 5.6. Its main features are as follows. In Fig. 5.1, a few seconds after the flight started, we see the effects of the wind on the aircraft. The compass shows that the plane is still heading due north but we see from the flight track that the plane has been blown to the east by the wind. The RDF shows that the beacon is no longer directly ahead, due to this wind displacement. The trainee initiates a right bank to compensate for the wind and (Fig. 5.2) makes it to the beacon although he was off course.

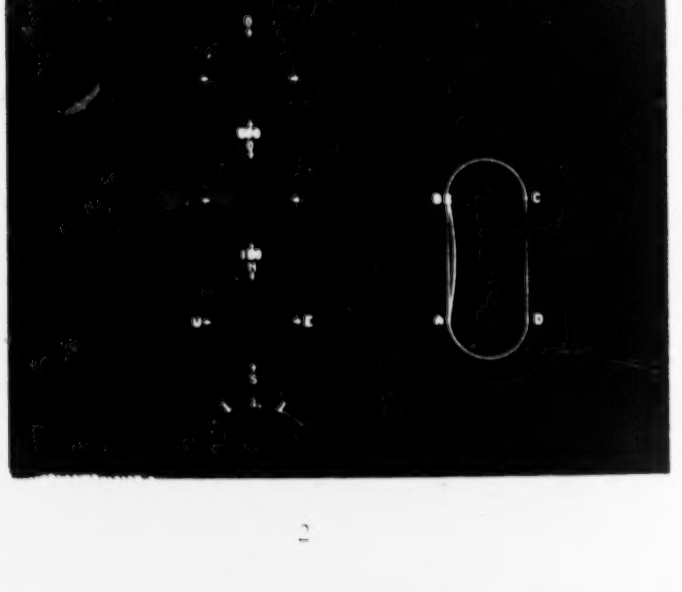
At Point B the trainee had initiated a standard 2-minute turn. But, because he failed to account for the wind, the turn is much too wide (Fig. 5.3), and he is off course again. As can be seen in Fig. 5.4, the pilot continues his turn, attempting to get himself back into the screen.

He now (Fig. 5.5) comes well into the pattern, possibly overcompensating because he realizes that the next turn will need to be tighter because he will be turning into the wind. Figure 5.6 shows that he waited a little too long to initiate this turn and, thus, went out too far. But he seems to be catching on.

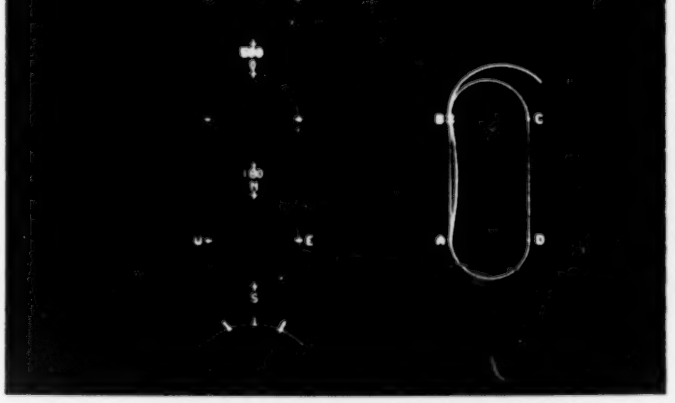
He should note that the radii of the two turns were different due to the wind even though both were made with the same nominal rate of turn. These differential wind effects would, of course, have been amplified if the wind had been stronger.

At this point the flight session was terminated. The analytic monitor was invoked and it typed out the following list of apparent errors.

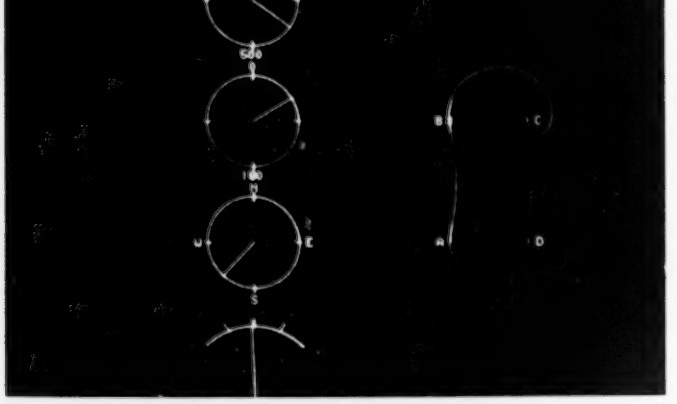
1



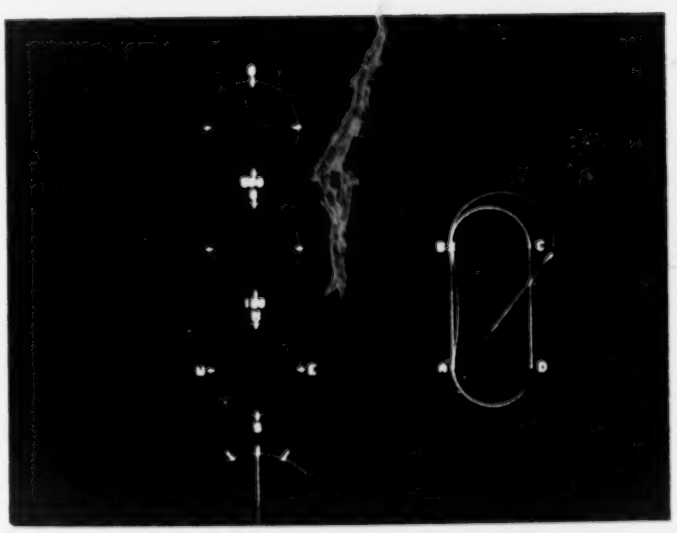
2



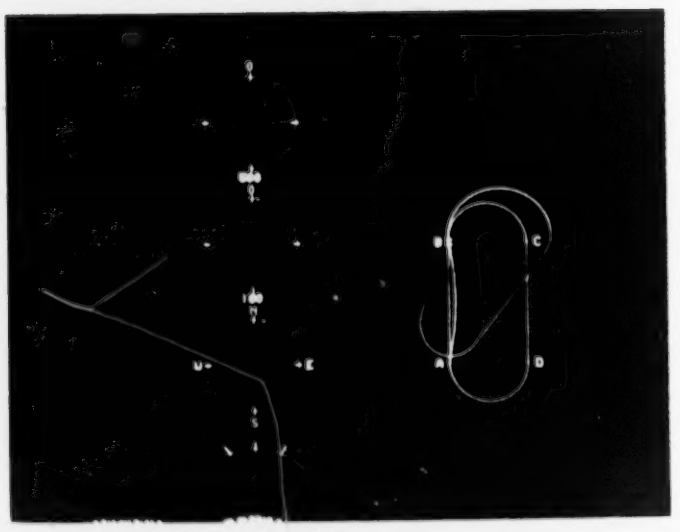
3



4



5



6

Fig. 5. Flight Sequence With Moderate Winds

NEGLECTING CROSSWIND EFFECT ON GROUND SPEED DURING OUTBOUND LEG

HOLDING ON SIDE OPPOSITE THAT FOR WHICH CLEARANCE WAS ISSUED

FAILURE TO VISUALIZE EFFECT OF WIND ON PATTERN

FAILURE TO VISUALIZE THE DIFFERENTIAL EFFECT OF WIND INBOUND AND OUTBOUND

In more extended sequences the trainee often compounds errors of these kinds. Such effects can be noted by the monitor. In the flight track shown in Fig. 6, for example, the trainee made two full circuits of the pattern. The effects that earlier errors had in creating subsequent difficulties were noted by the monitor. Also, it commented on failures to make use of previous knowledge.

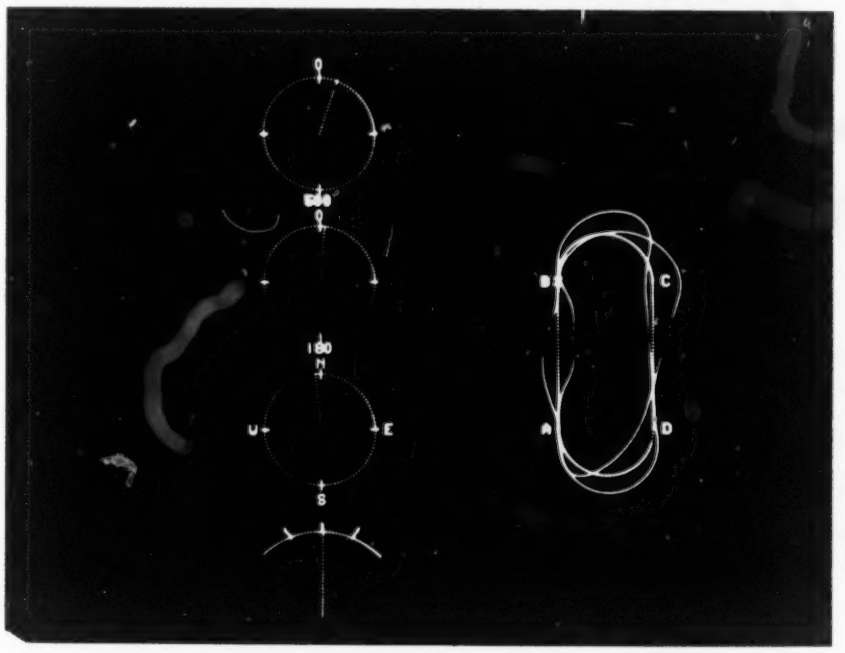


Fig. 6. A Two-Circuit Sequence

For example, on the first circuit the trainee correctly noted the drift due to the wind on the outbound leg as shown by his making the necessary compensation (the "double drift correction") on the inbound leg. However, he did not follow through with the proper wind correction the second time around (note the convex A to B arc) and the monitor commented on this failure.

The analytic monitor needs two data inputs. One of these is a table of the plane's locations at uniform times throughout the sequence. This actual flight position table is generated during the flight session and also can be used by the replay monitor to reproduce the flight sequence on the display. The other input is

a set of tables, one for each characteristic error in the list of standard holding pattern errors. Each of these characteristic error tables specifies an interval of allowable vehicle positions as a function of time, winds, pattern orientation, and desired accuracy. For example, the characteristic error of neglecting the effect of crosswind on ground speed is described in a table which gives the vehicle's approximate position in space every thirty seconds of flight, including the effect of crosswind speed and direction. The internal operation of the analytic monitor, then, is as follows. The program scans the entries in the trainee's actual flight position table and compares these with the corresponding time-position data generated from the characteristic error tables, to determine if there is an acceptable match. If so, the characteristic errors so identified are listed, as in the example above.

2.4 Testing and Evaluation

The holding pattern simulation and monitoring system was tested and evaluated in an instructional experiment described in this section. Our objective was to show that the use of monitoring techniques could enhance learning of complex perceptual motor tasks and thus provide a means of effectively extending the scope of useful application of computer assisted instruction. Our strategy was straightforward. We used the monitor system to train a number of subjects to "fly" holding patterns (at the computer) with some degree of proficiency. We then checked whether this skill carried over to the real task, by actual flight testing of the subjects.

Four subjects were involved in the experiments. They had flying experience spanning a wide range of hours. The least experienced subject was a neophyte -- he had no previous flight training. The most experienced one had about 200 hours of visual flight time, though no instrument flying time. (He has since gone on to obtain an instrument flight rating and then a license as a flight instructor for both visual and instrument training.) The two other subjects were a beginning student with six hours of dual (shared) flight training experience and an intermediate student with about 50 hours of flight training experience.

An instructional sequence, comprising an extensive series of holding pattern problems of increasing complexity, was given individually to the four subjects. In each case the work was carried out over four one-hour sessions at the computer. The first session was largely given to familiarize the subject with the instrument and flight track displays and the use of the joystick. The basic holding pattern problem (unrotated pattern, no winds) is to be flown with all displays, then only with the instrument display. Following this, a problem with a rotated pattern is given and then a return to the basic problem. The second session

introduces winds. The third and fourth sessions present more complicated problems in which the effects of variations in wind direction, wind speed, and pattern rotation must be considered jointly.

Throughout the sessions, the monitor diagnostics indicated each subject's particular areas of difficulties and thereby suggested appropriate situations to be presented in subsequent problems. Thus, the amount of time spent with each problem type and the pattern of progression to more complicated problems varied across subjects. Despite these differences, each took about the same overall time at the computer. (Typically each session included three significantly different problems and, with replay, the minimum time required to run through them all was about 30 minutes.)

As the subject carried out each flight his track was recorded. Following the flight, he called the replay monitor to rerun his work and review his performance. If a subject felt the need for further help, he could invoke the analytic monitor. The subject's work was also observed by a proctor. Following each flight, the proctor - using preassigned criteria - decided whether to proceed with a different problem situation. If more practice was deemed necessary, a variation of the current problem was given. After the session, the flight instructor who designed the sequence and the proctor, who was a novice pilot, briefly discussed the subject's work with him. The flight instructor then filled out flight log forms to assess and record the subject's progress. Also, the effectiveness of the monitors' outputs was judged and needs for improvements noted.

Students adapted very quickly to the simulator environment and their progress through the testing sequence was relatively direct and uncomplicated. Their comprehension of the basic aspects of instrument interpretation was rapid. It is interesting to note that after the first few flights the display of the flight path was considered more of a distraction than a help. This was true for all subjects. Each found that, in the case of anything more than a simple (no wind or pattern rotation) flight, the instruments gave a much more reliable indication of the situation than they could obtain by watching the flight path on the display.

The first flight of the second session introduced them to wind effects. Subjects were not told in advance from which direction the wind was coming, or the force of the winds which they were to encounter. Nevertheless, after only a few minutes of flight, each subject substantially improved his grasp of wind effects. By the end of the second session, three of the four subjects had learned to accurately estimate wind speed and direction. All subjects were correctly using the technique of

double drift compensation for winds during the third session and all found the critical comments of the replay monitor pertinent and useful during this phase of their training.

Throughout the four sessions the running of the replay monitor after flights was helpful to the subjects. When subjects were given the option of going ahead without running the replay monitor, they usually wanted to use it. They preferred the running "play-by-play" commentary of the replay monitor to the global error summary provided by the analytic monitor. It is interesting to note that on several occasions during the middle sessions, subjects were able to anticipate when the replay monitor was about to make a comment, and often, what that comment would be. During this phase each subject was recognizing his own difficulties and learning the appropriate action needed for overcoming them.

The training sessions were conducted in the spring of 1970. Three of the four subjects were flight tested in late spring and summer of that year. The flight instructor who accompanied the subjects and supervised their aerial sessions was a professional pilot with many years of experience as an instrument instructor. The subjects were each taken aloft and put on a course towards the Radio-Direction-Finder beacon at a small airport in the Boston area. A hood was placed over the subject's eyes to prevent him from looking out of the airplane's windows, while allowing full view of the instrumentation in the cockpit. He was given the problem of ascertaining when he had reached the beacon, and after obtaining the bearing of the runway from a standard aeronautical chart, of establishing and maintaining a holding pattern for this runway over the beacon. He was then given control of the aircraft.

In his test session, which took approximately an hour, a subject was given several flight approaches. Under the circumstances prevailing, a single session was sufficient in each case to test whether a subject could proficiently and consistently execute holding maneuvers under instrument conditions. The instructor reported that all subjects performed exceptionally well. They demonstrated facility with the use of the equipment and good comprehension of the principles involved in performing the holding task under moderate wind conditions. Despite the gusty air prevailing in each flight, none of the subjects was even significantly off course. They clearly showed that they had learned to correctly compensate not only for moderate winds but also for gusts changing appreciably both in direction and speed throughout the flights.

In conventional instrument flight training, two-to-four hours of pre-flight work is typically required to introduce the holding pattern task. Such pre-flight training is not in itself

sufficient for preparing trainees to successfully perform holding pattern maneuvers. Even with a good deal more experience and preparation on the ground, instrument trainees usually have significant difficulties in orientation in their first attempts at flying holding patterns. To attain a modicum of skill, trainees require at least another two-to-four hours of training in the air. Thus, the success which our subjects showed in transferring their skill from the computer training situation to actual flight was noteworthy.

Our experiment was limited in many ways including sample size. Nevertheless, despite the wide range of previous flight experience among subjects, their required training times and their subsequent performance were strikingly uniform. Each subject received four hours of pre-flight training at the computer and this amount of time was substantially required in all cases. The most advanced subject could not have attained the required level of proficiency in much less than three hours of computer simulation work and the least advanced subject would not have benefited appreciably from more than an additional hour of practice at the computer. Also, the three subjects who were flight tested performed their tasks in very much the same way. They each flew six patterns. The performance of the most advanced subject was flawless. The other subjects maintained most of their patterns in virtually error-free fashion, with only occasional minor mistakes which they speedily noted and corrected. The fourth subject, the neophyte trainee, was not tested in flight because he did not have the experience needed for the parallel task of maintaining the airplane in flight. The instructor confidently stated that, if this subject could have flown the airplane at all, he would have had immediate success in flying holding patterns.

The effectiveness of the instructional programs used in the experiment is evident. These programs, particularly the task simulator and the diagnostic monitor, were specifically tailored to the holding pattern task. Appropriate instructional programs of the same kinds can also be designed for use with many other complex perceptual motor tasks. For example, several other tasks in the same area of introductory flight training including take-off, radio navigation techniques, traffic patterns, instrument scanning, and crosswind landing approaches, can be effectively treated in this way. Computer simulations of the required degree of realism and verisimilitude can easily be programmed. Moreover, a considerable knowledge of characteristic errors associated with these specific tasks exists. Using this body of information, instructional monitor programs can be developed and evolved experimentally to a point where they correctly diagnose the most important errors of a particular trainee and help find his underlying difficulties. Instead of pursuing this development, we chose to work with a different kind of complex task.

3. Instructional Monitors and Maneuvering Concepts

This area was chosen as a second one which involves complex behavior in real time mode, yet it is completely different from the first in the specific skills which are brought to bear. In the holding pattern task, the subject continuously applies course corrections, feedback time being negligible compared to human response times. Use of a PPI display, on the other hand, involves careful selection and acquisition of pertinent information from a very slow moving, complex display. The purpose of observation is not direct action, but isolation of potentially interesting configurations for further computational analysis. A side benefit of practicing maneuvering with a simulated PPI display is that the student gets a good conceptual framework for dealing with relative motions, a critical skill for nearly all maneuvering situations.

3.1 The Real Task

The PPI operator is presented with a crowded display from which to extract a relatively small amount of important information. The display can include echoes corresponding to a large number of ship movements and, in addition, those corresponding to stationary objects such as coastlines, buoys, and radar beacons. Classification of echoes, particularly those of the latter types, is often difficult and is further complicated by the appearance of many forms of spurious signals such as those due to sea and rain clutter and to multiple echoes.

Collision avoidance is a particularly important application utilizing the PPI display. Here, identification of potentially dangerous objects is sought as early as possible after their appearance on the screen. This task is very difficult, partly because of the obscurations described above, and, to a greater degree, because of the extreme slowness of apparent motions. If the PPI display is set to a scale of one screen inch corresponding to one nautical mile of actual distance, a motion of 10 knots is seen on the screen as a motion of 1/6" per minute. Although precise calculations can only be performed by transferral of the situation to a maneuvering board, clearly, skill in making good estimates can be very helpful in screening interesting objects, with relative bearing in the general direction of own ship. Such estimates are particularly important when maneuvers to avoid collision are being planned because a change of course involves simultaneous consideration of all ships on the screen.

3.2 The simulation

A student works at a PPI screen, simulated on a graphics display, and a teletype terminal, both controlled by a minicomputer (a DEC PDP-8L). He is automatically presented with a given series

of estimation problems involving several different scenarios. An introduction to each problem is given on the teletype. The PPI sequence is presented. Then the specific question is asked. The answer is sometimes to be typed on the teletype and sometimes to be indicated by use of a "joystick" which moves a pointer on the simulated PPI screen. The subject's responses are automatically recorded for analysis, and he is also given feedback on the validity and outcome of his responses. The designer of such a problem sequence is given great flexibility in describing the format, presentation, and content of each question. In addition, he can make any of a large number of control options available to the student.

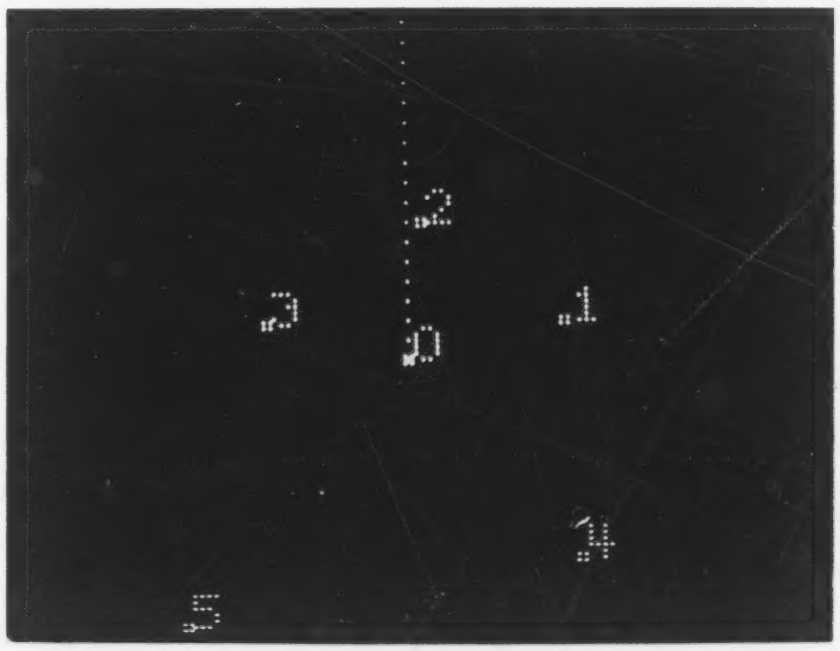
We next give, in full detail, an illustrative example of such an estimation problem via photographs and teletype text. It is taken from a sequence of problems which we used with students and which is described in detail later. The sequence photographs of the PPI screen (Fig. 7) show the developing situation. The student is also provided with an acetate overlay with five range rings for use with the display. The display is relative to own ship, at center, with North upward. The vertical dotted line is the heading marker. Numbers on the screen are provided, under computer control, to label each of the ships, which are shown as closely clustered squares. Explanations are enclosed within parentheses.

TYPE C TO CONTINUE (Typed by computer at termination of question #1)

C (Student's typing)

QUES #2
OBSERVE THE DIRECTION OF MOTION OF SHIP 1
TYPE C TO START

(Computer presents problem referring to configuration on screen)

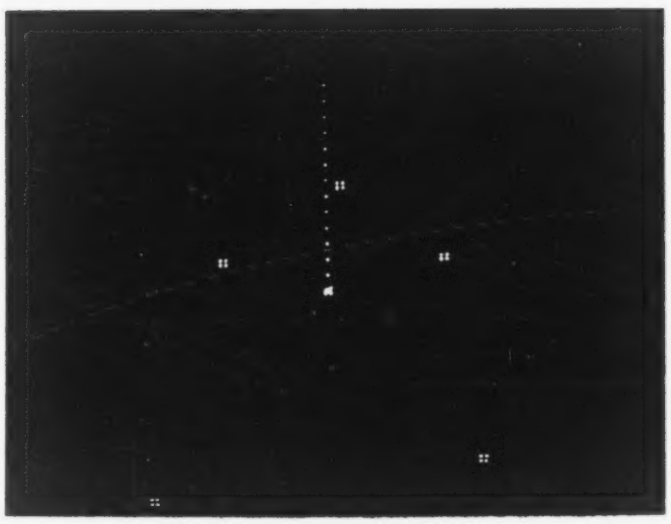


(Concurrent display showing own ship at center - labeled 0 - and five other ships)

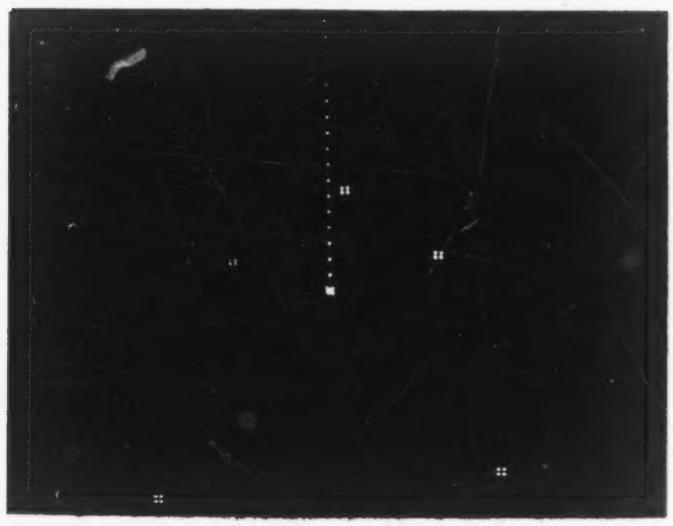
Fig. 7-1.

C

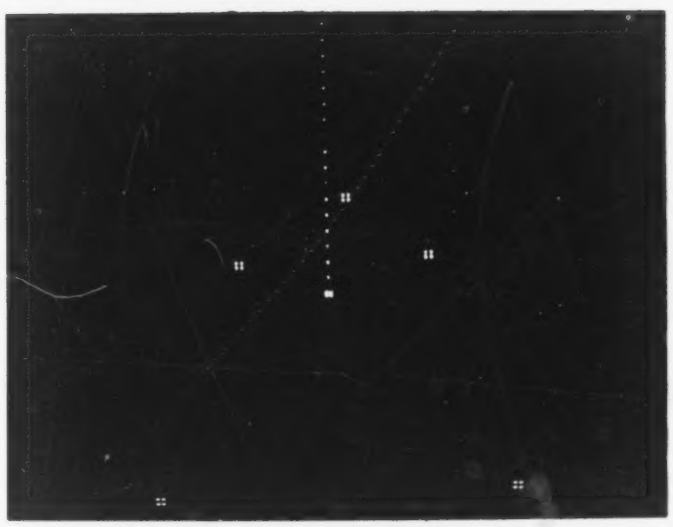
(Student types C initiating ship movements. Ship numbers no longer appear)



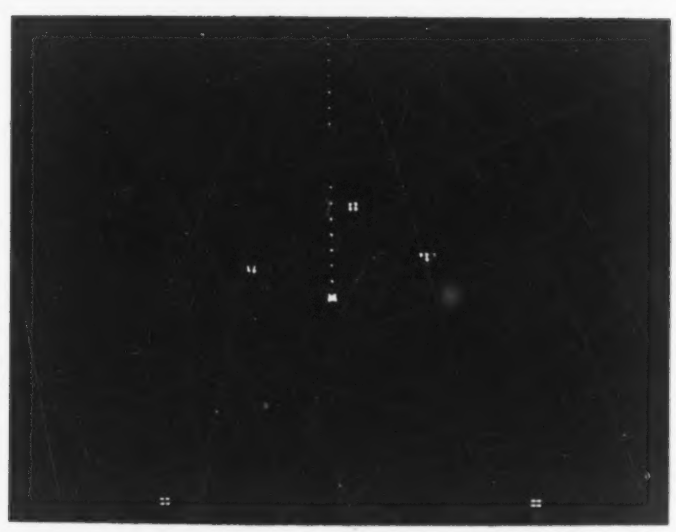
7-2



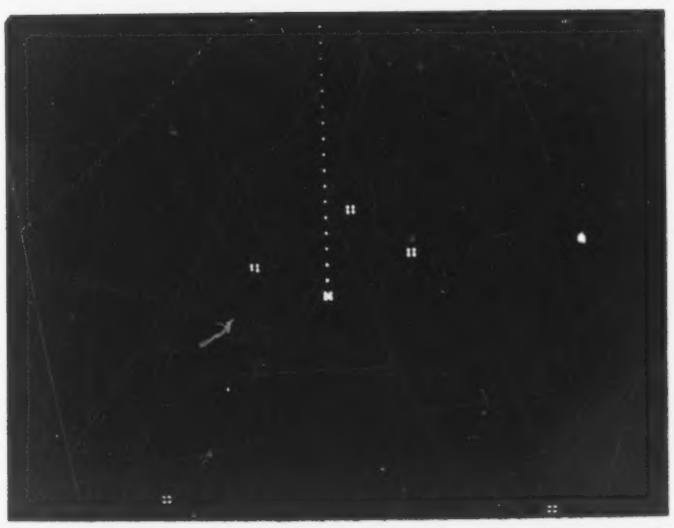
7-3



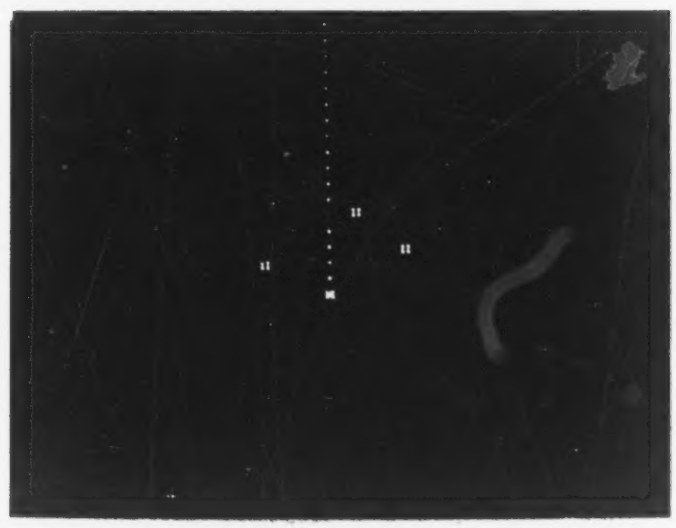
7-4



7-5



7-6



7-7

Figs. 7-2 - 7-7. PPI Display at 15, 30, 45, 60, 75, and 90 Seconds.

(The display freezes, ship numbers reappear, and the following question is simultaneously typed on the teletype.)

USE THE JOYSTICK TO INDICATE THE DIRECTION OF MOTION OF SHIP 1
BY POINTING ABOUT AN INCH AHEAD ALONG ITS CURRENT PATH
TYPE C TO CONTINUE

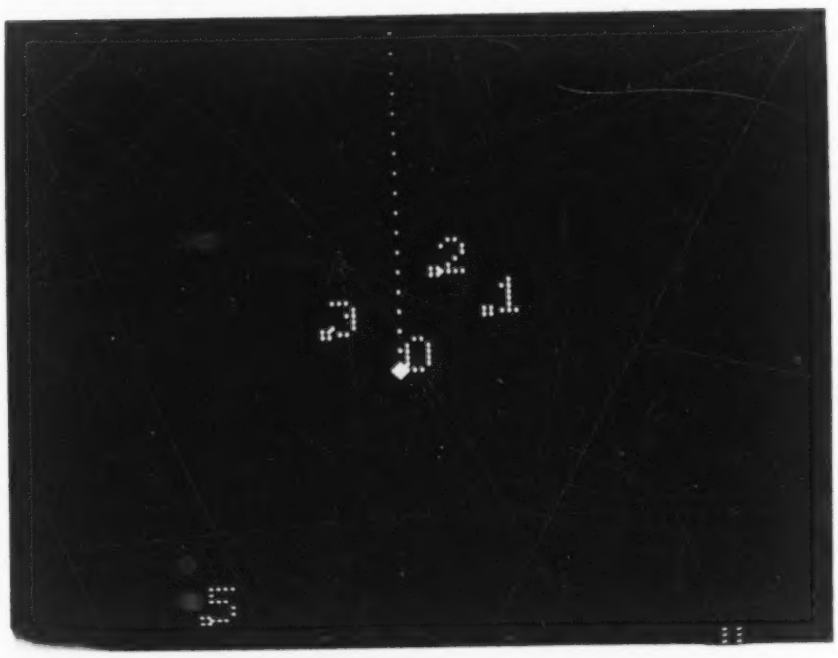


Fig. 7-8.
(Concurrent display)

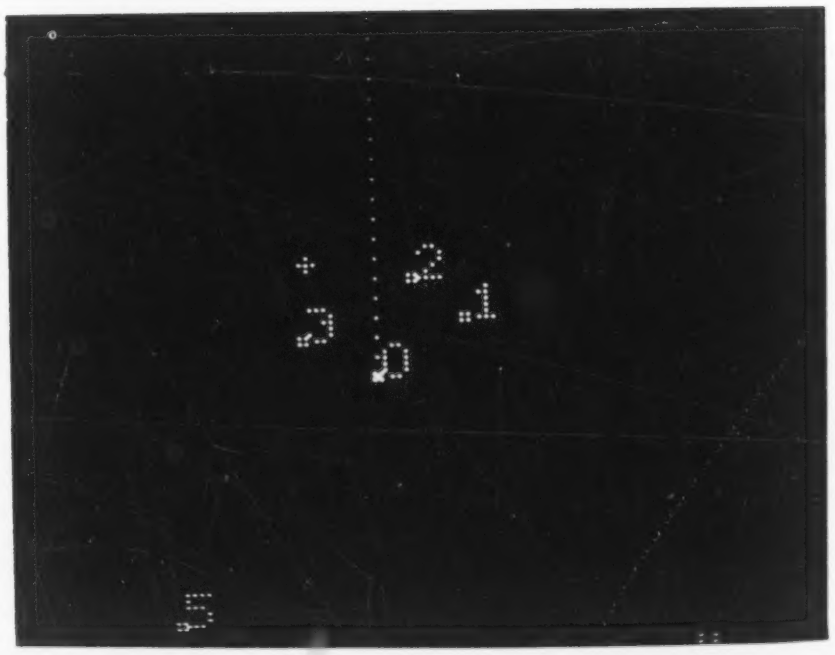


Fig. 7-9.

(Student indicates course by positioning the + marker controlled by the joystick - see north of ship 3)

C

(Student types C to continue)

(The ship motions are continued at a ten-fold increase in apparent speed to show outcome of situation)

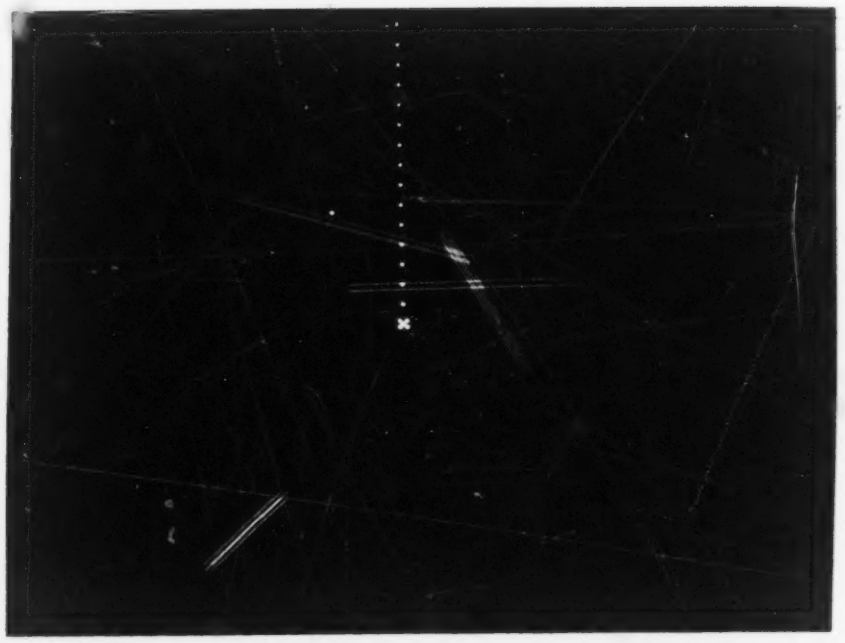


Fig. 7-10.

(A time exposure. The student sees that his estimate was a little too far north. He can now depress one of two switches, either repeating this question, or going on to the next one)

QUES #3
OBSERVE THE DIRECTION OF MOTION OF SHIP 1 (He chooses to continue)

The ship movements in the sequence above are summarized by the time exposure given in Fig. 7-11. The brighter segments correspond to the slower motions in the first part of the question prior to "fast motion".

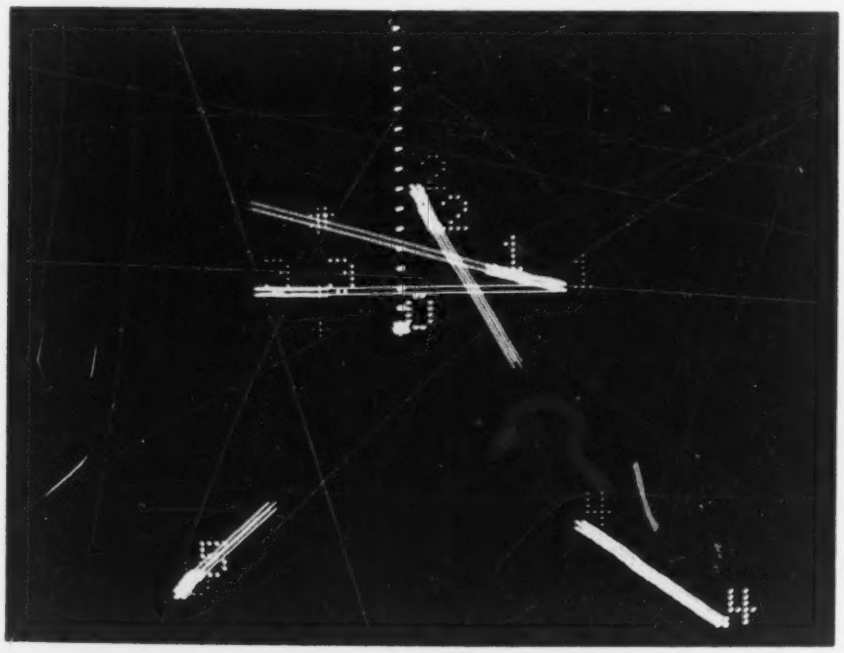


Fig. 7-11.

We next describe the facilities generally available for designing a problem sequence. A considerable degree of flexibility is available both in the situation that can be set up and in the question format used. Table 1 contains a list of control options available. Each option (except the first) can be used in two ways. The lesson designer can use an option under program control as in the case of appearance of ship numbers and "freezing" of the display in the above example. Alternatively, he can specify that an option be under control of the student -- as in the choice between advancing to the next problem and repeating the current one. (The student also had access to ship numbers, being able to turn them on at any time.) Option A is available only by means of a switch on the graphics unit and cannot be controlled by the computer. Thus, a single question consists of a combination of text presented on the teletype, display sequences, and a subset of the options described in Table 1. Student response is generally required at one or more places in the problem and this is done with the teletype, joystick, and console switches. These responses are punched out on paper tape for further analysis.

The lesson designer can also create a variety of different situations for display on the PPI screen. He can specify the presence of any number of ships, parameters available to him include speed and bearing as well as acceleration and rate of turn constants for each ship. Ship echoes can be given any shape desired, although these shapes do not change as the display progresses. Also, stationary objects such as buoys and shorelines can be specified.

Table 1. Control Options

A. The display can be run in storage tube mode so that moving ships leave trails. This is useful for familiarization purposes.

B. After completing any problem the student, by depressing either of two switches, has the choice of repeating it or going to the next one.

C. The display of heading marker, speed, and bearing can be turned on and off by console switches.

D. Numbers labeling the ships on the display can be turned on and off by console switches.

E. The display can be "frozen" at any point by typing F and restarted by typing C on the teletype.

F. A "joystick" can be used to move a point on the screen, either to answer questions or as a variable range marker.

G. After a question has been answered, the student can continue with a speeded up display to see the outcome of his predictions by typing C on the teletype.

H. Own ship's bearing and speed can be changed by typing any of the following

R followed by new bearing (turn right)

L followed by new bearing (turn left)

S followed by new speed in knots (change speed)

The display is relative to own ship, North upwards, and a range ring overlay and optional heading marker also are used. Figures 8 and 9, which are each composite photographs, show the PPI simulation for the case of own ship accelerating and decelerating, maintaining its bearing in each case.

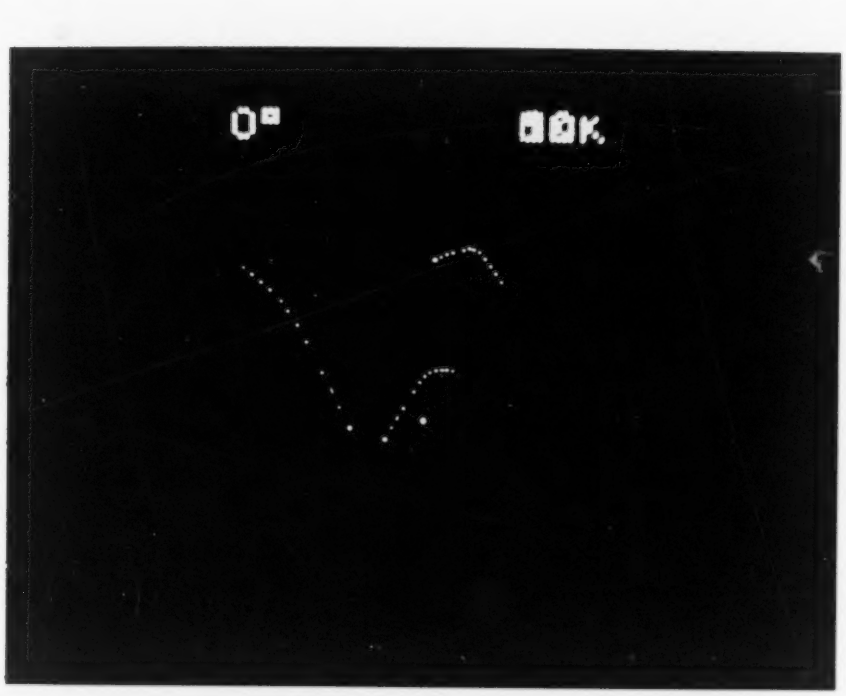


Fig. 8. Own Ship Proceeding on Course 000°. Accelerating from 10 Knots. Speed number is blurred because it is changing. Heading marker has been switched off and range rings removed.

Fig. 9. Own Ship Proceeding on Course 000°. Decelerating from 10 Knots to 0 Knots.

3.3 Experimental Set-up

We settled on the use of a DEC PDP-8L (one of several such small computers at BBN) as our research vehicle. This is the most satisfactory choice from several points of view. First, the PDP-8L is a very inexpensive computer, costing about $10,000, complete with teletype and oscilloscope graphics display. This, together with the wide availability of this configuration, will permit easy reproduction and extension of our work by other investigators. We used this computer as a dedicated unit. This makes real-time work easy, since there are no "time changes" due to system load to contend with. Finally, the computer and associated graphics are extremely reliable - there are none of the breaking-in and down time problems one encounters with sophisticated, state-of-the-art graphics systems.

Our computer configuration consists of a PDP-8L minicomputer with teletype, 4K core, and two programmable internal clocks (an option). An analog-to-digital converter is used to input the voltages across a standard resistor joystick. A digital-to-analog converter outputs voltages used to plot points on an oscilloscope screen. Our choice of oscilloscope, the Tektronix 611, combines a storage tube, a useful option for familiarization with a fairly large screen (7 x 9 inches). Thus, our simulated PPI screen can be 7 inches in diameter. A tape punch is used to record student responses.

The main computer program is a loop which sweeps a question table. The exact format of this table will vary with the format of the problems to be posed; as a specific case we take the problem sequence described next. There, all of the problems are of the same general form. The following quintuple for each entry in the question table suffices to prescribe an item.

Question number
# of initial ship configuration to be used (one of six in the example)
Display time
Pointer to initial text
Pointer to question text

This main loop also punches out student responses on paper tape and responds to those of the system options, described earlier, which are made available to the student.

The display is supported by a "ship table" within the computer containing complete information about all the ships displayed. This includes both their velocity and position vectors as well as acceleration characteristics, the last of these for the case in which the ship changes its course. The main loop, driven by a millisecond clock within the control processor, calls the display loop thirty times a second. This display loop sweeps through the table of ship values, refreshing the oscilloscope display.

The ship table is updated once a second to take changes of position due to non-zero velocity into account and to change velocities in the case of accelerated motion.

The programs themselves occupy about 1500 words of the 4000 word core. About 1000 additional words were used for the question table, ship table, and associated text and initial configuration data in the sample sequence next described. Thus, considerable empty space is left in memory for extensions of the system.

3.4 Experimental Problem Sequence

As a first step in designing an instructional monitor, we devised a short sequence of problems. Eleven experimental subjects were used, each of whom spent about an hour and a half on the 24 problems comprising the sequence. Clearly little training is possible over such a short time span. The object of this phase was, rather, to obtain data for use in designing subsequent training programs. These data were used to determine profiles of characteristic behavior against which systematic patterns of deviation could be contrasted. We first describe the problem sequence and then give an analysis of the data generated by its use.

We designed a sequence which was brief enough to administer in a single session (subjects required about 100 minutes to complete the sequence in most instances) and, at the same time, adequately comprehensive for us to find the characteristic behaviors present. Preparing a relatively short problem sequence, appropriate for this phase of monitor design, poses special problems. In a relatively small number of questions (24 in this case) one must vary both type of problem and parameters of each type over wide ranges. At the same time, however, the questions must be sufficiently similar to make feasible comparisons across questions so that effects of such variations can be seen. We chose four basic problem types with these desired properties and ordered these to form a coherent sequence of increasing difficulty.

The first and simplest type is estimation of bearing of a moving ship on the simulated PPI display. Only direction is involved here. The second asks the point at which a moving ship will intersect own ship's heading marker. Now, both a direction and a distance are involved. The third type of problem asks for the closest point of approach (CPA) to own ship. The subject must now determine two directions - the bearing of the ship of interest and, additionally, the perpendicular from the line thus estimated to own ship. The fourth and last set of problems asks the CPA of one ship to another ship, both in motion relative to own ship. Now, for the first time the element of time (or equivalently, velocity) is involved since the paths of the two ships are not sufficient to solve the problem. The time at which each point on each path is traversed is also needed for solution. This last problem type is particularly useful in connection with the basic skills required for course change estimates, as in collision avoidance and maneuvering. All ships used in these problems were given constant courses.

We used six questions of each type and therefore 24 questions in all. This allowed us to vary appropriate parameters extensively. Six initial ship configurations were prepared to be run through for each problem type. By using the same six configurations repeatedly for the four types, we facilitated comparisons across types. Although only one additional ship is required for the situations used in problem types one, two, and three, and two additional ships for the situation used in the last type, each configuration contained six ships to add a reasonable measure of complication. The display was uniformly maintained for 90 seconds in every case.

In order to draw further distinctions for assessing behavior patterns, each group of six questions was further halved. The first three questions within each problem type specified the ship(s) of interest in advance. The latter three only specified the ship in question after the simulation was completed. Thus, the subject in the latter situations had to "follow" all six ships on the simulated PPI.

Thus, there are four groups of six questions each, each group being subdivided into two subgroups of three questions each. Below, in Table 2, we give a sample teletype recording for each of the four major types of question.

Table 2.

Type 1. (Same as example in Section 3.2)
Ship of interest specified in advance.

```
QUES #2
OBSERVE THE DIRECTION OF MOTION OF SHIP 1
TYPE  C  TO START

                    (DISPLAY)

C

USE THE JOYSTICK TO INDICATE THE DIRECTION OF MOTION OF SHIP 1
BY POINTING ABOUT AN INCH AHEAD ALONG ITS CURRENT PATH
TYPE  C  TO CONTINUE
C
```

Type 2. Ship of interest specified in advance

```
QUES #9
OBSERVE THE DIRECTION OF MOTION OF SHIP 2
TYPE  C  TO START

                    (DISPLAY)

C

USE THE JOYSTICK TO INDICATE THE POINT AT WHICH THE PROJECTED
PATH OF SHIP 2 INTERSECTS THE HEADING MARKER
TYPE  C  TO CONTINUE
C
```

Type 3. Ship of interest not specified in advance

```
QUES #17
OBSERVE THE DIRECTION OF MOTION OF EACH SHIP ON THE DISPLAY
TYPE  C  TO START

                    (DISPLAY)

C

INDICATE THE POINT AT WHICH SHIP 1 WILL PASS CLOSEST TO OWN SHIP
TYPE  C  TO CONTINUE
C
```

Type 4. Ships of interest specified in advance

QUES #2Ø
OBSERVE THE DIRECTION OF MOTION OF SHIP 4 AND SHIP 5
TYPE C TO START

(DISPLAY)

C

INDICATE THE POINT AT WHICH SHIP 4 WILL PASS CLOSEST TO SHIP 5
TYPE C TO CONTINUE
C

3.5 Experimental Findings

There are special difficulties in judging and analyzing answers to the course estimation problems described above. First, perceptual difficulties enter significantly by way of greatly increasing the width of the subject answer distribution. Such perceptual difficulties are very much greater in PPI estimation problems than in, say, instrument flying problems because of the exceedingly small velocities involved. We will see, later, the strong, systematic variations of answer distribution width with respect to ship velocity and distance of "correct" answer. To further complicate the analysis of data, it must be kept in mind that the subject is in a learning situation. This means that his performance must be evaluated conditionally in the context of his position within the training sequence.

In the preliminary stage of monitor design, described in this part of the report, subject responses were evaluated "by hand" after the termination of the test run. The paper tapes, which had been punched with the answers during the test runs, were processed by another computer program to convert the answer data into more useful form. This output was searched by the experimenter for significant behavior patterns. In later design, all analysis should be done directly by the computer immediately after each response. The form of such analysis is described below, following a description of our research findings.

The results of a test run using the 24 problem sequence described above were 24 coordinate pairs, each relating to a specific ship for each problem. A natural center for the coordinate system in each case is the position of the ship being asked about, at the termination of the display simulation. The first six problems involved only a direction estimate with respect to this final ship position; the others involved a distance estimate as well.

The responses are effectively represented as polar coordinate pairs, the first elements being the deviation in distance from the exact answer, and the second, the angular deviations. By putting answers in this form, we eliminate the absolute position and orientation of the answer on the display, and replace the arbitrary X, Y coordinate system with a much more natural one. The only important parameter variation across questions remaining was that of relative difficulty. To eliminate this parameter, we found the standard deviation for each coordinate in each problem using the data of all the eleven subjects tested. We then normalized the answers by dividing each by its standard deviation. (Actually, to avoid weighting errors, all this was done in X-Y coordinates and converted to relative polar coordinates at the last step.)

Table 3 contains the values of the important parameters for each of the 24 questions. These are the velocity of the ship of interest (in proportional units), the distance of the exact answer from the final position of the ship of interest, and the distance and angular standard deviations.* Two of these parameters -- the answer distance, R(ANS), and standard deviation in distance, SIGMA(R) -- are not meaningful for the first six questions in which only an estimate of angle was required. For comparison purposes, it is convenient to use a broader classification of velocity and answer distance. Such a scheme is given in Table 4 and is far more convenient than numerical values for making rough comparisons.

The strong dependence of answer accuracy (standard deviations in the answers) is seen easily from Tables 3 and 4. It is immediately apparent that high ship velocities result in more precise angular determination (questions 3, 10, 14, 16, 17, 20) and that short answer distances result in more precise distance estimates (questions 9, 13, 23). One would not expect such a relation between SIGMA(R) and VELOCITY or between SIGMA(T), the angular standard deviation, and R(ANS) nor do such correlations exist.

---

*Answers have been carried far beyond the two digits of significance due to formatting idiosyncrasies of the programming language used (BASIC).

Table 3.

QUESTION	VELOCITY	K(ANS)	SIGMA(K)	SIGMA(T)
1	271.529			0.440591
2	318.798			0.375236
3	588.313			0.260307
4	192			0.793861
5	135.765			1.65124
6	229.085			0.622358
7	294.156	441.38	199.651	0.451352
8	229.085	469.553	572.318	0.720063
9	208	16	13.9818	0.727675
10	411.359	640.4	172.726	0.276071
11	294.156	429.921	255.137	0.52299
12	318.798	419.981	344.641	0.84947
13	288.555	73.7564	80.6302	0.59719
14	411.359	585.969	134.702	0.233788
15	304	336	89.8969	0.28532
16	565.685	384.666	84.6023	0.256388
17	413.299	545.234	131.798	0.255887
18	294.156	610.94	161	0.294362
19	294.156	746.705	217.926	0.325983
20	565.685	360.624	130.686	0.392682
21	294.156	374.06	214.212	0.70206
22	229.085	440.71	125.262	0.441052
23	294.156	26.8701	34.5435	0.846489
24	294.156	513.408	122.635	0.260802

Table 4.

	VELOCITY	R(ANS)
1	MEDIUM	
2	MEDIUM	
3	HIGH	
4	LOW	
5	LOW	
6	MEDIUM	
7	MEDIUM	HIGH
8	MEDIUM	HIGH
9	MEDIUM	LOW
10	HIGH	HIGH
11	MEDIUM	HIGH
12	MEDIUM	HIGH
13	MEDIUM	LOW
14	HIGH	HIGH
15	MEDIUM	MEDIUM
16	HIGH	MEDIUM

	VELOCITY	R(ANS)
17	HIGH	HIGH
18	MEDIUM	HIGH
19	MEDIUM	HIGH
2Ø	HIGH	MEDIUM
21	MEDIUM	MEDIUM
22	MEDIUM	HIGH
23	MEDIUM	LOW
24	MEDIUM	HIGH

Table 5 contains processed data for two typical test runs. The top row for each contains the subject's initials and his average distance, angular, and total deviations. To cancel the effects of problem complexity, the deviation from correct answer of each problem is divided by the standard deviation. The table then gives the "normalized" deviations for each question (last two columns) as well as the numerical values of the student answer relative to the final ship position (R and T). Data in this form are relatively easily used to find patterns of deviation.

Table 5.

JGC	Ø.566397	Ø.744802	Ø.6556	
QUESTION	R	T	DEV(R)	DEV(T)
1	588.802	3.78238		Ø.198969
2	683.52	3.50036		1.36692
3	441.814	Ø.734161		5.78540E-2
4	520	1.32209		-7.93950E-2
5	446.067	4.14428		1.34777E-2
6	576.056	5.18846		-2.37535
7	574.943	4.15526	Ø.664179	Ø.464541
8	519.199	Ø.588003	-Ø.48158	-Ø.568362
9	35.7771	5.17604	1.18459	-Ø.814507
1Ø	648.346	6.00828	Ø.131343	-1.Ø8843
11	811.123	5.09656	1.26708	-Ø.540907
12	915.956	4.26046	1.48051	1.52716
13	51.225	3.81633	-1.Ø3921	Ø.313137
14	499.472	Ø.556902	-Ø.569402	1.46256
15	281.823	Ø.113792	-Ø.369879	Ø.285541
16	379.389	3.88224	Ø.584045	1.81275E-3
17	562.053	3.2271	Ø.356528	1.14561
18	531.744	3.92699	-9.44342E-2	-Ø.522706
19	854.354	5.51765	Ø.852754	-Ø.389035
2Ø	27Ø.7Ø3	4.11619	-Ø.475185	Ø.83315
21	293.721	5.22478	-5.32105E-2	-Ø.94289
22	43Ø.813	4.33188	1.172	-Ø.44819
23	4Ø	3.14159	-2.33863E-2	2.31608E-2
24	386.161	6.Ø5328	-Ø.685454	2.41157

WBW	0.50897	0.620045	0.564508	
QUESTION	R	T	DEV(R)	DEV(T)
1	848.151	3.16046		-1.21258
2	778.018	3.06955		0.218812
3	605.733	0.982794		1.01301
4	515.985	1.05165		-0.420055
5	600.853	3.19488		-0.561488
6	634.073	0.514451		0.210258
7	397.432	3.84149	-0.224933	-0.230658
8	557.25	0.683709	-0.415095	-0.435448
9	17.8885	5.81954	-9.48215E-2	0.0698164
10	624.82	5.12372E-2	-4.85847E-3	9.29519E-2
11	521.72	5.33442	0.132775	-8.60931E-2
12	400	3.14159	-0.0165755	0.210026
13	96.3328	3.98575	-0.479766	0.596821
14	625.281	6.40150E-2	0.364579	-0.645702
15	338.373	6.1647	0.259174	-0.528566
16	403.822	4.12439	0.872841	0.946249
17	560.514	3.18442	0.344848	0.97884
18	649.726	4.04919	0.63837	-0.107587
19	533.846	5.94722	-0.617965	0.928718
20	476.386	3.9983	1.0987	0.532928
21	475.31	6.16509	0.794498	0.396475
22	352.817	5.28781	0.549338	1.7192
23	16	1.63322	-0.718165	-1.75876
24	490.159	5.16874	0.162581	-0.98005

If a student performs equally well across all problems, relative to other students, then his normalized deviations will vary in a random manner over his 24 response pairs. This is generally not the case, however, and there are a variety of error patterns which can be found. One searches for correlations between deviations (both in magnitude and sign) and each of the following:

(A) difficulty of problem as measured by size of standard deviation
(B) speed of ship of interest
(C) distance of answer from final ship position
(D) whether or not the ship(s) of interest is specified in advance.

In addition, the following patterns are important.

(E) learning, as indicated by improvement in score. This factor did not enter into the present test runs because of their relative brevity.

(F) correlation between distance and angular errors

(G) correlation between absolute angle (direction on screen) and deviation of angle.

If we search the data presented in Table 5 with respect to these criteria, we find that for subject JGC there is a simple pattern in his angular estimate deviations. He did very much better, relatively, on "immediate" problems, that is, ones with a small answer distance. This is seen clearly below:

	Low	Medium	High
Average Angular Deviation	0.3	0.5	1.0

There is a similar strong correlation between relative error in distance and ship velocity. Thus, JGC works well with small distances but has trouble in retention when larger distances are involved, either directly as distances or as net ship displacements. The only significant pattern in subject WBW's answers is that he gives considerably poor angular estimates when high ship velocities are involved. This, again, indicates a difficulty in retention.

The experimental findings described above are the result of a relatively small-scale preliminary investigation. This means that "noise" due to random variations in subject performance is much larger than would be the case for a large-scale study. The main way in which this noise complicates the analysis is in underestimating the magnitude of relative deviations in responses. Part of the standard deviation is due to real perceptual complexity of the task and is not reducible. A large part, however, is due to small sample size. This is clearly seen by the fact that even the simplext problems, presenting little in the way of perceptual barriers to estimation, gave rise to substantial standard deviations. If this latter component is eliminated, or substantially reduced, patterns of deviation would appear much more sharply in subject responses. Thus, not only would the patterns described above be easier to find but the detection of more complex ones that are presently obscured would be possible. Furthermore, the larger sample size makes possible the use of standard statistical tests such as bivariate correlations, and single numerical coefficients derived for use in detecting the appearance of patterns of error. This greatly facilitates the implementation of a completely automatic monitoring program.

The next step, then, in furthering this development is to replicate the experiment using a considerably larger subject base to enable more precise statistical measurements. The diagnostic procedures used can then be incorporated with the simulation to provide an immediate monitoring capability.

4. Summary and Conclusions

In those kinds of learning situations where the acquisition of perceptual or motor skills is integral to a problem-solving task, the classical computer assisted instructional framework is inadequate. In such situations the student's work must be assessed, not on whether he can answer questions about how to do the task or even on how well he can describe effective procedures for doing it, but on whether he can actually do it. Thus, given that the task of interest can be reasonably simulated on a computer, the CAI procedures needed are instructional monitors like those we have been developing.

In earlier work[1,2] we designed two procedure-oriented instructional monitors that tested a student's ability to describe complex procedures of many kinds. (These contrast with the task-oriented monitors described above which are expressly tailored for use with particular tasks.) With these monitors students were given a problem-solving task, typically in a mathematics, physics, or engineering context. The student was supposed to solve the problem by writing a program in an elementary programming language. In using the more general of these two instructional monitors, SIMON, the student tests his program by comparing its operation for any number of particular inputs he chooses, with that of a correct program included by the lesson designer. When the student thinks his own program is working properly, or when he wants advice about how it is incorrect, he informs SIMON. SIMON tests the student's program and looks for cases where it fails. Further, it can inform the student which of his inputs are not relevant and whether he has neglected some relevant ones.

The complex tasks of interest to us in connection with maneuvering, navigation, and piloting are more naturally learned by doing them than by describing how they should be done. Thus, a task-oriented monitor provides a more natural instructional framework for these tasks than does a procedure-oriented monitor like SIMON.

Such task-oriented monitors must be given very specific information about characteristic performance errors and behavior patterns exhibited by trainees carrying out the task. This information is highly task-dependent -- the observable errors shown by trainees learning to fly crosswind holding patterns are ostensibly different from those shown in learning crosswind landing approaches, even when the underlying difficulties of a particular trainee are the same in both situations. Given descriptions of specific error patterns, then, the monitor compares a particular trainee's performance data with these to detect and identify his conspicuous difficulties. The program for doing this follows along straightforward and fairly general lines.

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1. SIMON-A Simple Instructional Monitor, W. Feurzeig, P.Wexelblat, R.C. Rosenberg, IEEE Trans. on Man-Machine Systems, December 1970; also BBN Technical Memorandum, August 1970.
2. Bond Graphs and ENPORT in Elementary Physics Instruction, R.C. Rosenberg, W. Feurzeig, P. Wexelblat, IEEE Trans. on Man-Machine Systems, December 1970.

We have worked on instructional monitors in two v ry different situations. In the work on the instrument flight task of maintaining a holding pattern, we started with a knowledge of characteristic well-defined trainee behavior patterns. These data were of sufficient scope and quality to permit us to write programs for detecting and diagnosing individual trainee errors. In the work on ship maneuvering, on the other hand, we had to build up such knowledge of characteristic behavior and error patterns preparatory to implementing monitoring programs for training in collision avoidance and other maneuvering tasks of interest.

In the work on the holding pattern task, we demonstrated the feasibility and usefulness of the monitoring approach as a training tool. Further, we evaluated several other tasks in flight training to show the extensibility of this approach to them. In particular, we were able to describe characteristic behavior and error patterns in programmable form for several critical tasks in flight training including instrument scanning, radio navigation, and crosswind landing approaches. We think that an introductory flight training course could be substantially enhanced by a digital simulator and monitor system along the lines initiated.

In the area of ship maneuvering, we performed a preliminary experiment designed to elicit characteristic trainee behaviors in estimating relative ship motions. The analysis indicated that the framework used in that work is appropriate for identifying these patterns. A substantially extended experiment involving about 100 subjects is needed to define the basic patterns precisely enough to isolate an individual's errors with high confidence. Using these characteristic error data, instructional monitors to provide training in basic concepts of ship maneuvering designed along substantially the same lines as the holding pattern monitor, appears feasible.

Heretofore, most developments of CAI techniques have been directed toward purely intellectual training tasks in areas such as statistical estimation, organic chemical analysis, or grammatic French usage. The techniques we have explored seem richly appropriate for extending CAI to complex tasks involving mechanical and perceptual as well as intellectual components. This kind of extension will be particularly important in making many areas of technical training generally accessible.

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